# THE OHIO JOURNAL OF SCIENCE

VOL. 58 | JULY, 1958 | NO. 4


## THE EFFECTS OF POLLUTION ON A MIDWESTERN STREAM


ARDEN R. GAUFIN†

*Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio*


A year-round study of environmental conditions in the Mad River, one of the few trout streams in Ohio, was initiated in September, 1952. The objectives of the study were threefold: first, to determine how wastes discharged to the stream were affecting the physical-chemical environment; second, to determine the effects on the composition of the benthic-macroinvertebrate populations in the river; and third, to evaluate the significance of such organisms as indicators of ecological changes produced in the stream by pollution.

The Mad River is a tributary of the Great Miami River which enters the Ohio River near Cincinnati. It rises in Logan County, Ohio, and flows in a turbulent manner much of the distance to its confluence with the Great Miami and Stillwater rivers at Dayton. It is about 65 miles long and has an average gradient of six feet per mile. Its profile is typical in that the steeper slopes are in the headwaters and the flatter slopes are in the lower sections.

The 632 square mile drainage area of the Mad River contains the greatest concentration of permeable material in Ohio. Its course lies principally between two morainal ridges with extensive permeable drift covering the main valleys and uplands. In the neighborhood of Urbana, there are numerous small bog lakes and along much of the course of the river springs help to maintain a relatively high sustained flow. The major portion of ground-water inflow occurs between Springfield and Dayton.

The stream has been dredged and channeled between West Liberty and Tremont City, a distance of 20 miles. This section, as a result, has very few deep pools and presents many of the characteristics of a young stream.

In 1951 the Ohio Department of Health reported that four sewered municipal areas, with an estimated population equivalent (B.O.D.)* of about 150,000, discharged their wastes into the Mad River (McDill, 1951). All four have sewage treatment plants which, in 1949, were effecting a combined population equivalent reduction of about 40,000. Only the Fairborn plant provides secondary treatment.

The major portion of the wastes being discharged into the river comes from Springfield, a city of around 98,000 (1950 census). In 1949, the total wastes released from this source had a population equivalent of 75,000.

All sewage and industrial wastes from the city of Urbana, with an estimated population of 9,000, are discharged into Dugan Run about four miles upstream from its confluence with the Mad River. In Urbana several small manufacturing plants are connected to the municipal sanitary sewers and two large paper mills

†Present address: Zoology Department, University of Utah, Salt Lake City, Utah.

*Population equivalents as given by the Ohio Department of Health are based upon an average of 0.167 pound of 5-day, 20° C, B.O.D. per capita per day for domestic sewage.

discharge waste directly into Dugan Run. The total population equivalent of the Urbana area wastes in 1949 was 36,000 with 30,000 of this equivalent discharged into Dugan Run. Sewage from the town of West Liberty, 14 miles north of Urbana, is also discharged into the river, but contributed a population equivalent of less than 2,000.

## PROCEDURES

During the course of this study, special attention was given to environmental variations accompanying seasonal changes such as floods, turbidity, bottom growth, temperature, pH, dissolved oxygen, and total alkalinity. Twelve stations, representative of the various sections of the stream, were selected for sampling

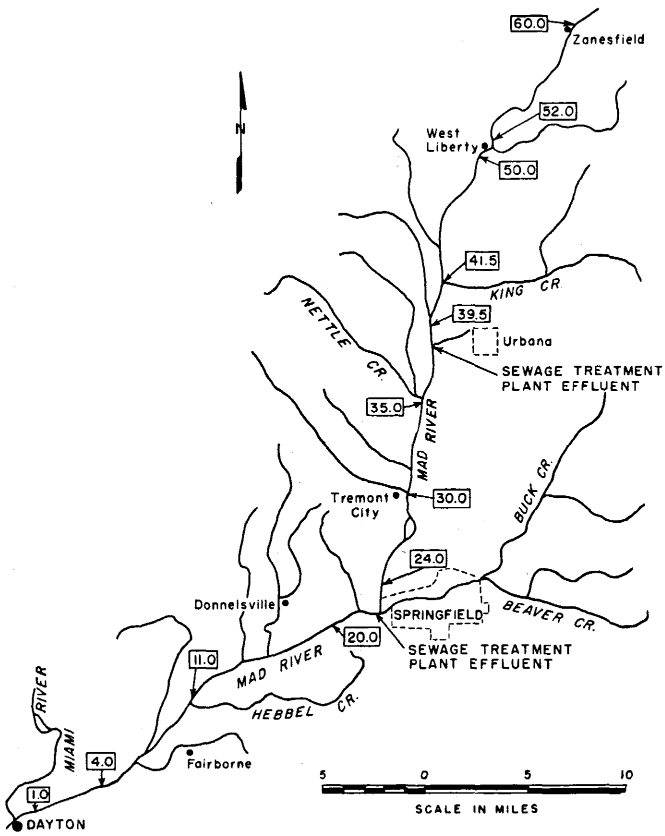


FIGURE 1. Mad River drainage basin.

purposes. The sampling areas also were selected to reveal seasonal changes in the stream above and below any major source of pollution. These stations are designated by the distance in miles upstream from the mouth (fig. 1).

Water samples were taken at each of these stations during October, 1952, January and May, 1953, and October, 1955, for the determination of dissolved oxygen, pH, $CO_2$, methyl orange and phenolphthalein alkalinity, and temperature. The samples taken in 1955 were used to determine changes which had occurred in the stream during the two-year interval following the initial year of the study. The follow-up study was prompted by several extensive fish kills noted between

Urbana and Springfield from 1953 to 1955. Diurnal variations in physical and chemical conditions were determined by taking hourly samples at six of the stations during November, 1952.

During each of the months listed, bottom samples were taken in pools, runs, and riffles. Collections to determine the relative abundance of different types of organisms in various sections of the stream were made with a Needham handscreen sampler 1 yard wide and 30 inches high. An area of bottom approximately 1 yard square was covered at each sampling, and the organisms collected were observed, classified, and enumerated in the field.

## RESULTS

### *Physical and Chemical Conditions*

The average annual precipitation for the Mad River watershed is approximately 38 inches, distributed fairly evenly throughout the year. However, from September 1952 to June 1953, precipitation was 7 to 10 inches below the annual average for that period. As a result of the decreased rainfall, only one scouring flood (May 17–22, 1953) occurred in the stream during the entire study.

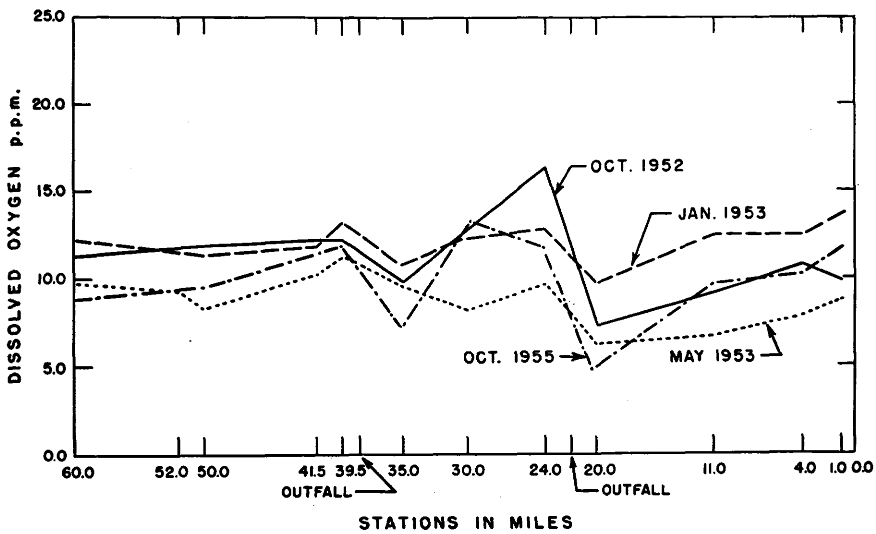


FIGURE 2. Variations in dissolved oxygen. Mad River.

Records of the U. S. Geological Survey (Paper 1275, 1953) showed considerable variation in the discharge from the river during the period October 1, 1952, to September 30, 1953. The maximum daily flow at Zanesfield near the headwaters was 170 c.f.s. on March 3; the minimum flow of 0.9 c.f.s. occurred on January 5 and 6 and during several days in September. At a point six miles above the mouth of the stream the maximum daily flow was 5,340 c.f.s. on May 23, and the minimum was 139 c.f.s. on September 30. These flows were ⅓ to ⅙ below the maxima and minima normally expected at these stations.

Because of the numerous springs that discharge into it, the temperature of the Mad River is cooler in spring, summer, and autumn and warmer in winter than other streams of comparable size in the area. For example, for September 1939, the Public Health Service (Report 517, 1942) reported the average temperatures of the Mad, Miami, and Stillwater rivers above their confluence at Dayton to be 63°F, 69°F, and 70°F, respectively. During January and February, 1953, the

Mad River averaged 42°F while the Miami and Stillwater rivers had 35°F averages. During May and early June 1953, the Mad River had a 63°F average, the Stillwater had warmed up to 70°, while the Miami averaged 78°F. As a result of its lower temperatures the Mad River supports a typical cold-water fauna, while the other two streams contain the warm-water species characteristic of the region.

Determinations of dissolved oxygen above and below the major waste discharges at Urbana and Springfield indicated a heavy organic load as there was a decrease in dissolved oxygen below the outfalls to less than 40 percent of saturation. After receiving the Urbana wastes, the dissolved oxygen content dropped 2 to 4 p.p.m., the amount varying with the temperatures and flow. Below Springfield the reduction was even greater, from 3 to 9 p.p.m. However, inspite of this reduction, the minimum dissolved oxygen value recorded was 3.8 p.p.m., or 34 percent of saturation. This concentration was encountered 20 miles downstream from

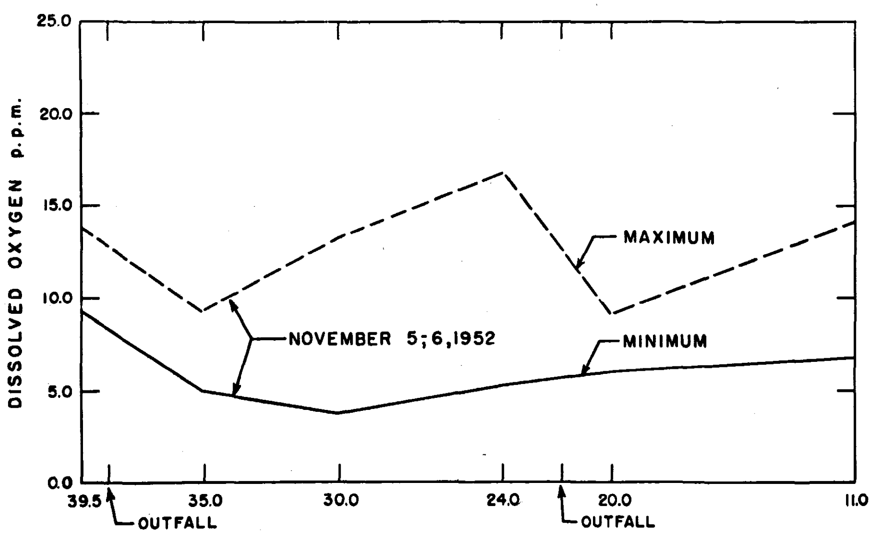


FIGURE 3. Range in dissolved oxygen. Mad River.

Urbana, at Tremont City, during a 24-hour sampling run conducted on November 5–6, 1952. It is probable that the dissolved oxygen content is lower than this during summer nights when temperatures are higher. Inasmuch as the river flow at Springfield on every sampling date was double to triple the critical flow of 125 c.f.s. determined by the Ohio Department of Health (McDill, 1951), oxygen depletion would undoubtedly have been much greater in September when the minimal flow was 120 c.f.s. for several days. A comparison of the dissolved oxygen concentrations in the stream under autumn, winter, and spring conditions is made in figure 2. The data points represent single grab samples taken during daylight hours. The diurnal variations in dissolved oxygen occurring above and below the major sources of pollution on November 5–6, 1952, are shown in figure 3.

Along with the decrease in dissolved oxygen there was a corresponding increase in free carbon dioxide. Free carbon dioxide concentrations of 2.6, 7.9 and 10.5 p.p.m. were obtained below West Liberty, Urbana, and Springfield, respectively in October 1955. No free carbon dioxide was found at any of the other stations during that period.

The pH of the river at the various stations varied so little as to be insignificant. The maximum pH value recorded was 8.4 in the daytime at several of the clean-water stations. The minimum of 7.5 was recorded above Springfield at night during the 24-hour run. Phenolphthalein and methyl orange alkalinity tests indicated the water to be rich in carbonates and bicarbonares, a condition which usually favors high productivity of bottom fauna and other life. The alkalinity of the water expressed as calcium carbonate content varied from a minimum of 249 p.p.m. at Zanesfield during May 1953, to a maximum of 341 p.p.m. in the lower part of the stream during October 1955.

Of the chemical factors considered, distribution of the stream fauna appeared to be more closely related to dissolved oxygen concentration than to any other factor noted. However, of equal or greater importance in the stream section below Urbana and Springfield was the influence of wood fibers in the paper mill wastes discharged at Urbana. Data supplied by the Chief Engineer of United Cardboard Co., during October 1955, revealed that each of the paper mills in that city releases 900,000 to 1,000,000 gallons of wastes per day directly into Dugan Run. Wastes from the two plants have a combined 5-day B.O.D. of 4,141 lbs. These wastes consist in part of a suspension of very finely divided paper particles carried in the wash waters from the plants. These particles gradually settle to the bottom of the river but they give a milky-white appearance to the water for a distance of 15 to 20 miles below the entry point. When settled, they form a blanket over the bottom and over anything else to which they can adhere. Few organisms can exist in this substratum because of suffocation and it is also unsuitable as an attachment base for most aquatic invertebrates.

*Biological Conditions*

In conducting this study, emphasis was placed on determining the effects of the wastes on the macroinvertebrate population of the river. The study was restricted to this group because of their larger size and more distinctive morphological characteristics which facilitate their identification under field conditions. In addition, it is believed that most representatives of the group have longer life histories than the microbenthic fauna and are thus better fitted for indicating past ecological conditions in any given area.

A total of 166 species representing 122 genera of macroinvertebrates were collected and identified during this study. This diverse fauna belonged to the following orders or families: mayflies (Ephemeroptera) 19 species; stoneflies (Plecoptera) 21; caddis flies (Trichoptera) 15; alder flies (Neuroptera) 3; beetles (Coleoptera) 24; dragonflies and damsel flies (Odonata) 9; water bugs (Hemiptera) 6; true flies (Diptera) 42; crayfish and shrimps (Crustacea) 5; springtails (Poduridae) 1; water mites (Hydrachnidae) 1; snails and clams (Mollusca) 8; leeches (Hirudinea) 3; segmented worms (Oligochaeta) 6; flat worms (Planaridae) 1; and round worms (Nematoda) 2.

The study revealed distinct differences in the number of species and the faunal associations occurring in the stream above and below the principal waste sources.

The largest number of species, 58, was taken in the clean headwater section above Zanesfield in May 1953. Nearly half of this number (47%) were species of mayflies, stoneflies, caddis flies, and beetles which were limited entirely in their distribution to the cleanest sections of the stream. No one species was found in numbers exceeding 25 per square yard while 27 species were represented by less than three individuals per square yard of bottom area. The average number of species of macroinvertebrates found in different sections of the stream on the four sampling dates is shown in figure 4.

The stimulatory effects of a moderate amount of organic enrichment on the productivity of the stream were clearly demonstrated below West Liberty. During the May survey, this station revealed only ¼ less species than were found upstream, but four species exceeded 50 specimens per square yard, and one species, *Ephemerella simplex*, averaged over 100 individuals per similar size sample. The composition of the fauna, however, was changed decidedly with the disappearance of such stoneflies as *Isoperla transmarina*, and *Isogenus duplicatus*, and such caddis flies as *Chimarra obscura* and *Helicopsyche borealis*, and with the common occurrence of such facultative forms as *Chironomus decorus*, *Macrobdella* sp., and *Limnodrilus* sp. With adequate oxygen and an increased food supply, forms, characteristic of both clean water and organic enrichment, found niches in this environment which enabled them to thrive.

The limiting and selective effects of heavy organic enrichment on the fauna were most in evidence below Springfield. Not only was the number of species drastically reduced but the composition of the population was also greatly changed. The maximum number of species taken in this section was 14 in October 1952; the minimum number was 6 during the following January. With the exception of a single specimen of mayfly and caddis fly, all of the organisms encountered were those usually found in organically enriched areas. Those collected included the

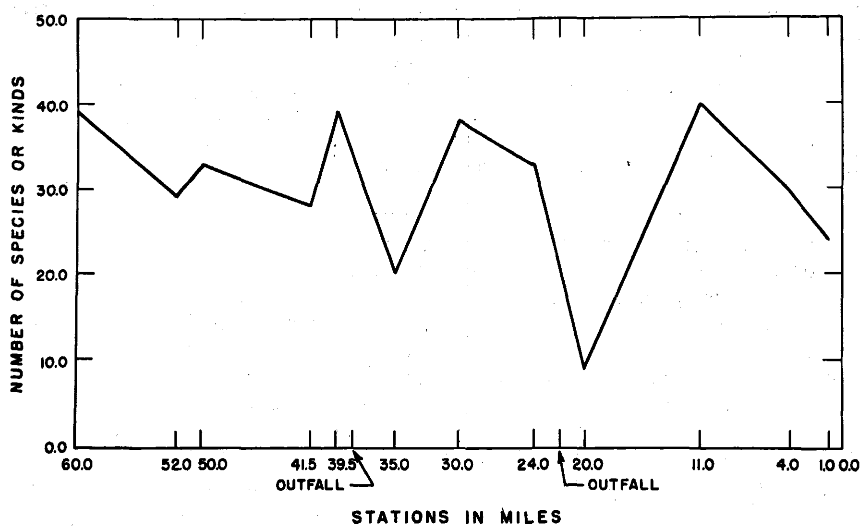


FIGURE 4. Macroinvertebrate distribution. Mad River.

pulmonate snail, *Physa integra*; sludge worm, *Limnodrilus* sp., leeches, Macrobdellidae, and red blooded midge larvae, *Chironomus riparius*, all of which occurred in large numbers. All of the organisms found in this section were characterized by special adaptations for obtaining oxygen or by very low oxygen requirements.

The movement of paper wastes downstream from Urbana between 1952 and 1955 resulted in some interesting changes in the faunal numbers and composition at several of the stations. In May, 1953, as many as 27 different species were taken at a point three miles below the confluence with Dugan Run, and 41 species occurred at Tremont City 5 miles farther downstream. By October 1955, these numbers had been reduced to 9 and 11 species, respectively. During 1953, such mayflies as *Baetis* sp., *Caenis* sp., and *Stenonema rubromaculatum*, and midge larvae of the subfamily Hydrobaeninae, were found in numbers exceeding 10 per square yard on the upper surface of floating masses of leaves of *Potamogeton* sp. While pulmonate snails, leeches, and sludge worms were common on the bottom, they did not exceed 20 specimens per square yard. By October 1955, all of the mayflies and other gill breathing forms had disappeared and the remaining snails, leeches, and sludge worms had increased considerably.

At Tremont City in 1953, thirteen of the 41 species taken were mayflies, stoneflies, and caddis flies with *Caenis* sp. exceeding 100 per square yard. By 1955, all groups except midges (*Chironomus decorus*), water sow bugs (*Mancasellus* sp.), pulmonate snails, leeches, and sludge worms had disappeared.

At the beginning of the study in October 1952, the section of the river just above Springfield displayed the physical-chemical characteristics of an organically enriched stream but the macroinvertebrate fauna was still diversified. Forty-six species of macroinvertebrates were taken including 12 species of mayflies, stoneflies, and caddis flies. With the exception of large numbers of the mayfly, *Baetis* sp., which exceeded 150 per square yard, the stream supported a varied and well balanced aquatic community. By 1955, the number of species had been reduced to 15, but those that remained reached tremendous numbers. In the October 1955 survey, large numbers of *Hydropsyche* sp. (over 200 per square yard) existed in the faster, deeper riffles, associated with numerous *Mancasellus* sp. In the shallower riffles Planaridae were so abundant as to completely cover the hand screen in a single sample. In excess of 1,000 specimens were counted from one square yard. Associated with these forms were lesser numbers of pulmonate snails, leeches, and sludge worms.

The lower twenty miles of stream below Springfield showed much the same response to the added wastes throughout the course of the study. The section of stream north of Fairborn, or approximately 11 miles below the Springfield sewage treatment plant outfall, displayed a varied well balanced aquatic community at all times indicating complete recovery from the wastes received above. By the time the stream reached Dayton, however, after receiving additional wastes below Fairborn, most of the less tolerant mayflies, caddis flies, and stoneflies had disappeared.

## DISCUSSION

As stated previously, there were three principal objectives of this study. The effects of organic enrichment on the physical-chemical environment and on the benthic macroinvertebrate population in the river have already been presented. An evaluation of such organisms as indicators of the ecological conditions under which they existed in various sections of the stream will now be discussed.

Numerous lists of indicator organisms have appeared in various publications (Richardson, 1921, 1928; Mackenthun et al., 1956; Weston and Turner, 1917). In other investigations, the pollutional zones have been indicated by means of diagrams showing the percentage of so-called clean-water, facultative, and pollutional forms occurring in the areas studied (Surber, 1953; Wilson, 1953). Many of these lists have been based on the ecological classification originated by Kolkwitz and Marsson (1908, 1909) and later published by Whipple (1948). Comparison of these different lists will show that there is an appreciable lack of agreement as to the true status of many of the organisms. This lack of agreement is a result of regional differences in the species present and in the environment, and is conditioned by the point of view of the investigator, the mechanism of evaluation, the types of pollutants, and other factors.

A satisfactory classification of organisms as indicators of organic enrichment depends upon several criteria. These criteria have been discussed in more detail by Gaufin and Tarzwell (1952), but are briefly presented here to emphasize some of the difficulties involved in classifying organisms into definite "pollutional" categories. Many organisms which occur in large numbers in extremely enriched areas may also be found in limited numbers in cleaner situations. In this connection, it should be pointed out that the mode of occurrence of the forms is just as important as their presence or absence in a given area. For example, while a few specimens of *Physa integra*, *Macrobdella*, and *Limnodrilus* were found in certain microhabitats in the clean water areas in the Mad River, they were found in much larger numbers (50 or more per square yard) and occupied considerably more space in the organically enriched sections. This was due to an increased food supply as well as a decrease in competition caused by the elimination of intolerant species.

In differentiating between clean water and facultative forms, it is likewise important to consider the numbers represented and adaptations involved. An occasional mayfly, stonefly, or caddis fly may be found during winter in stream sections which are septic in summer. When these insects drift into such a stream from nearby tributaries, they may live for considerable periods of time because the septic zone of summer often has acquired an adequate dissolved oxygen supply during winter. Before such isolated examples are taken as evidence that the forms involved are facultative, an investigation as to their source and their abundance in the source area is advisable.

Consideration of the structural and physiological adaptations is often very important in arriving at a better definition of the habitat preference of the forms being considered. In general, air breathers are not limited by deficient dissolved oxygen and can be considered tolerant of environmental conditions produced by excessive organic enrichment. Conversely, most gill breathers are dependent directly upon the amount of dissolved oxygen available in the water and are intolerant of any environmental change which reduces the dissolved oxygen level below their requirements.

At the beginning of this study, the sources and extent of organic and industrial pollution in the river were initially determined by reference to data published by the Ohio Department of Health (McDill, 1951). This information was later confirmed by direct observations and by chemical and physical data collected during 1952–53 and 1955. No additional waste treatment facilities had been installed by any communities or industries along the river since the Health Department Survey. Below Springfield for at least five miles the river displayed a grayish color and produced foul sewage odors; sticky blackened sludge deposits with offensive odor were everywhere in evidence, and gas bubbles could be seen rising frequently from deep pools during the warmer months. The stream below Urbana was milky white for a distance of 15 to 20 miles and black sludge deposits were common in pools and in *Potamogeton* beds in the entire stretch between Urbana and Springfield, particularly during October, 1955.

Dissolved oxygen concentrations in the stream just below the Urbana sewage outfall to three miles below Springfield varied during the night of the 24-hour sampling run conducted on November 5–6, 1952, from 34 to 53 percent of saturation. Following Suter and Moore's (1922) classification of zones of pollution and self purification, this entire section of stream constituted the lower end of a zone of degradation or the upper end of a zone of active decomposition.

In classifying the organisms collected during the study, citations in the literature, mode of occurrence, relative abundance, physiological and morphological adaptations, and number of records of each species were taken into account. Species averaging more than 50 specimens per square yard were considered numerous, those ranging from 5 to 50 per square yard were common, and those occurring less abundantly than 5 per square yard, scarce or few. The species or genera of organisms collected, their distribution according to Suter and Moore's pollutional zones, and their pollutional classification are given in table 1.

In comparing the indicator status of the Mad River specimens with citations of the same species in the literature, it was found that the environmental classifications selected by the author were in fairly close agreement with those given by Schiffman (1953) for Illinois fauna, by Mackenthun et al. (1956) for Wisconsin, and by Surber (1953) for Michigan. However, over half the material collected

TABLE 1

*Distribution of macroinvertebrates, Mad River, 1952–53, 1955*

Intolerant Organisms*

Ephemeroptera (14)
*Ephemera simulans*, *Ephemera guttulata*, *Ephemerella simplex*, *Ephemerella* sp., *Heptagenia maculipennis*, *Heptagenia* sp., *Hexagenia limbata*, *Isonychia* sp., *Leptophlebia* sp., *Paraleptophlebia* sp., *Potamanthes* sp., *Stenonema interpunctatum*, *Stenonema tripunctatum*, *Stenonema rubromaculatum*.

Plecoptera (20)
*Acroneuria evoluta*, *Allocapnia granulata*, *Allocapnia nivicola*, *Allocapnia recta*, *Allocapnia viviparia*, *Alloperla mediana*, *Brachyptera fasciata*, *Hastaperla brevis*, *Isoperla bilineata*, *Isoperla confusa*, *Isoperla decepta*, *Isoperla minuta*, *Isoperla transmarina*, *Isoperla orata*, *Isoperla signata*, *Isogenus duplicatus*, *Neophasganophora capitata*, *Nemoura* sp., *Paragnetina media*, *Perlesta placida*.

Trichoptera (10)
*Caborius* sp., *Chimarra obscura*, *Glossosoma* sp., *Helicopsyche borealis*, *Hydroptila* sp., *Hydropsyche* sp., *Hydropsyche slossonae*, *Pycnopsyche* sp., *Rhyacophila lobifera*, *Rhyacophila fenestra*.

Hemiptera (2)
*Mesovelia* sp., *Microvelia* sp.

Neuroptera (2)
*Chauliodes* sp., *Sialis* sp.

Coleoptera (5)
*Helichus lithophilus*, *Psephenus lecontei*, *Stenelmis crenata*, *Stenelmis sexlineata*, *Simsonia quadrinotata*.

Diptera (13)
*Calopsectra* sp., *Cricotopus tricinctus*, *Cryptochironomus* sp., *Corynoneura* sp., *Limnochironomus* sp., *Microtendipes pedellus*, *Polypedilum illinoense*, *Stictochironomus* sp., *Anopheles punctipennis*, *Antocha* sp., *Eriocera* sp., *Pseudolimnophila* sp., *Paradixa* sp.

Hydrachnidae (1)

Facultative Organisms**

Ephemeroptera (5)
*Baetis* spp., *Caenis* spp., *Stenonema ares*, *Stenonema heterotarsale*, *Stenonema pulchellum*.

Plecoptera (1)
*Taeniopteryx maura*.

Trichoptera (5)
*Cheumatopsyche* sp., *Hydropsyche bronta*, *Hydropsyche betteni*, *Hydropsyche cuanis*, *Hydropsyche simulans*.

Odonata (9)
*Agrion maculatum*, *Argia* sp., *Enallagma* sp., *Ischnura* sp., *Hetaerina americana*, *Boyeria vinosa*, *Dromogomphus* sp., *Progomphus* sp., *Libellula lydia*.

Hemiptera (4)
*Belostoma* sp., *Gerris* sp., *Hesperocorixa* sp., *Notonecta* sp.

Neuroptera (1)
*Corydalis cornutus*

Coleoptera (19)
*Agabus stagninus*, *Berosus* sp., *Dineutes americanus*, *Enochrus pygmaeus nebulosus*, *Haliplus* sp., *Hydroporus* sp., *Hydroporus wickhami*, *Hydroporus mellitus*, *Laccobius agilis*, *Laccophilus* sp., *Laccophilus fasciatus*, *Laccophilus maculosus*, *Peltodytes* sp., *Peltodytes 12-punctatus*, *Peltodytes edentulus*, *Peltodytes lengi*, *Paracymus* sp., *Tropisternis lateralis*, *Tropisternis natator*.

Diptera (28)
*Anatopynia decolorata*, *Anatopynia dyari*, Chironomidae (unidentified), Chironomini, *Chironomus decorus*, *Cricotopus* sp., *Cricotopus bicinctus*, *Cricotopus trifasciatus*, Hydrobaeninae, *Hydrobaenus nivoriunda*, *Chironomus* sp., *Metriocnemus* sp., *Pentaneura melanops*, *Polypedilum fallax*, *Polypedilum* sp., *Procladius* sp., *Atherix* sp., *Palpomyia flavipes*, *Tipula abdominalis*, *Chrysops* sp., *Tabanus* sp., *Argyra* sp., *Rhoderiodes* sp., *Limnophora* sp., *Simulium vittatum*, *Simulium* sp., *Stratiomys discalis*, *Ephydra* sp.

Crustacea (5)
*Orconectes* sp., *Asellus* sp., *Mancasellus* sp., *Gammarus* sp., *Hyalella* sp.

Poduridae (1)
*Podura* sp.

Mollusca (5)
*Ferrissia* sp., *Goniobasis* sp., *Helisoma* sp., Pleuroceridae, *Pisidium* sp.

TABLE 1—(*Continued*)

Hirudinea (1)
*Glossiphona* sp.
Oligochaeta (2)
*Aeolosoma* sp., *Helodrilus chlorotica*
Nematoda (1)
*Paragordius* sp. (1)

Tolerant Organisms***

Diptera (1)
*Chironomus riparius*
Mollusca (3)
*Musculium* sp., *Sphaerium* sp., *Physa integra*
Hirudinea (2)
Macrobdellidae, *Macrobdella* sp.
Oligochaeta (4)
*Dero* sp., *Limnodrilus* sp., *Tubifex* sp., Lumbriculidae
Planaridae (1)

*Largely restricted to Clean Water Zone: Dissolved oxygen between 75%–115% of saturation (Hwy 33, N.W. Liberty, Hwy 36, Hwy 29).
**Found in both Clean Water Zone and Zone of Degradation: Dissolved oxygen between 40% to 115% of saturation (Hwy 68, S.W. Liberty, Hwy 235, North Dayton, Hwy 69, Tremont City (1953), Hwy 70 (1953).
***Most abundant in Zone of Active Decompositions: Dissolved oxygen between 1% to 40% of saturation (Hwy 55, Lower Valley Pike, Tremont City (1955), Hwy 70 (1955).

from the Mad River was not classified in the literature consulted, thereby eliminating any chance for comparison of such specimens.

Reference to table 1 will reveal that most of the species classified as being intolerant are mayflies, stoneflies, caddis flies and other strictly gill breathing forms which were restricted to the clean water sections of the stream. Two or three records of a gill breathing species occurring in very limited numbers in the non-clean water zones were not considered sufficient to change its classification to the facultative category. If, however, such a species was common or numerous in the zone of degradation or zone of active decomposition and was evidently a resident form, it was considered as being facultative. Such species as *Stenonema ares*, *Taeniopteryx maura*, *Hydropsyche betteni* and *Corydalis cornutus* were found to be surprisingly tolerant of organic enrichment and were placed in this category.

Most of the surface breathing beetles and water bugs such as *Tropisternis natator*, *Peltodytes lengi*, *Laccophilus maculosus*, *Hesperocorixa* sp., and *Belostoma* sp. were found in both clean and polluted areas in about equal numbers and were also classified as being facultative. Their abundance depended primarily upon the availability of food, suitable cover, competition, etc., and their method of respiration made them largely independent of the dissolved oxygen supply.

Approximately one-third of the organisms considered as being facultative were Diptera. Representatives of this order were found in the stream in both the clean water and polluted zones in many ecological niches. However, two-thirds of the species collected were more abundant in the Zone of Degradation than elsehwere. Their ability to thrive in the presence of considerable organic pollution is due to the possession by some species of special respiratory tubes for obtaining oxygen from the surface, to the presence in others of hemoglobin for storing and transporting oxygen, or to very low oxygen requirements.

Comparatively few species were encountered which could be considered as "pollution" preferring forms. Such invertebrates as the midge larvae, *Chironomus riparius*; pulmonate snail, *Physa integra*; leech *Macrobdella* sp., and sludge worms, *Limnodrilus* sp. and *Tubifex* sp., while present in limited numbers in clean waters, were found so abundantly and predominately in the most heavily enriched sections that they could reasonably be called pollutional species.

In conclusion, populations dominated by the gill-breathing insects such as mayflies, stoneflies, and caddis flies were largely restricted to the clean water sections of the stream and their absence denoted excessive organic pollution or low dissolved oxygen. Likewise, the presence of a population consisting primarily of species adapted to live under very low dissolved oxygen levels as *Tubifex* and *Limnodrilus*, or those able to secure their oxygen directly from the air as do *Culex pipiens*, *Eristalis bastardi*, and *Physa integra*, was equally indicative of heavy organic pollution.

## SUMMARY

A year-round study of environmental conditions in the Mad River was conducted by the writer during 1952–53. The period was unusually dry, resulting in a precipitation deficiency in the drainage basin from 7 to 10 inches below the annual average of 38 inches. As a result, the average flow of the stream was only half the annual average reported for the preceding seven years.

Because of numerous springs which discharge into it, average seasonal temperatures of the river were found to be 7° to 15°F lower than in streams of comparable size in the area. Chemical analyses of water samples taken above and below the major sources of pollution at Urbana and Springfield reflected the waste discharge by a decrease in dissolved oxygen of from 2 to 9 p.p.m. and a corresponding increase in free carbon dioxide from 0.0 to a high of 10.5 p.p.m.

Of equal importance were the effects of paper mill wastes discharged at Urbana. Each of the paper mills in that city releases between 900,000 to 1,000,000 gallons of waste per day into Dugan Run, a tributary of the river. These wastes have a combined 5-day B.O.D. of 4,141 lbs. In addition they blanket the bottom with paper fibers, making it totally unsuitable as a habitat for most species of macroinvertebrates.

A total of 166 species representing 122 genera of macroinvertebrates were collected and identified. The largest number of species, 58, was taken in the headwater section above Zanesfield in May 1953. Nearly half of this number (47%) were mayflies, stoneflies, caddis flies, and beetles, and were limited entirely to the cleanest sections of the stream. The selective effects of heavy organic enrichment on the fauna was most in evidence below Springfield. Only 14 species were collected at any one time in this area and, with the exception of one mayfly and one caddis fly, all of the organisms encountered were what have been classified as facultative or polysaprobic forms.

The movement and accumulation of paper wastes downstream from Urbana between 1952 and 1955 resulted in some interesting changes in faunal numbers and composition at several of the stations. In May 1953, as many as 27 different species were taken three miles below Urbana, 41 species occurred 5 miles farther downstream, and 46 species were collected just above Springfield. Included were 12 species of mayflies, stoneflies, and caddis flies. By October 1955, these numbers had been reduced to 9, 11, and 15 species respectively, and all gill breathing forms except one species of *Hydropsyche* had disappeared. This form was found only in fast riffle areas. The leeches, snails, sludge worms, and water sow bugs that remained occurred in tremendous numbers.

By considering the species composition, abundance, and adaptations of the macroinvertebrates collected in the various pollutional zones which were indicated by physical-chemical tests, it was possible to classify such organisms into three categories based upon their reactions to organic enrichment, clean water, facultative, and pollution-preferring categories. Nearly 50 percent of the species taken in the river above Urbana were clean water forms, with less than 10 percent of the pollution-preferring species represented. By contrast, 50 percent to 100 percent of the macroinvertebrates occurring below Urbana during the 1955 survey were "pollution-tolerant" forms with no clean water forms present immediately below Urbana and Springfield.

ACKNOWLEDGMENTS

The advice, active assistance, and cooperation of Public Health Service personnel and others have been of considerable value in this investigation. The suggestions of Clarence M. Tarzwell were of great aid in planning the project and preparing the manuscript. Personnel of the Robert A. Taft Sanitary Engineering Center who helped in obtaining the physical-chemical data were: C. M. Tarzwell, C. M. Palmer, W. C. Howard, George Paine, and Harold Walter. Special thanks are due George Paine for his identification of the Diptera.

REFERENCES

Federal Security Agency, Public Health Service. 1942. Ohio River pollution survey; Miam and Little Miami River Basins. Final report to the Ohio River Committee. III, 517.

**Gaufin, A. R.** and **C. M. Tarzwell.** 1952. Aquatic invertebrates as indicators of stream pollution. Public Health Report 67: 57–67.

Geological Survey Water Supply Paper 1275. 1953. Surface water supply of the United States. Part 3–A, Ohio River Basin except Cumberland and Tennessee River Basins 352–371, U. S. Government Printing Office, Washington, D. C.

**Kolkwitz, R.** and **M. Marsson.** 1908. Oekologie die pflanzlichen Saprobien. Ber. d. Deut. Bot. Gesell. 26a: 505.

———. 1909. Oekologie die tierischen Saprobien. Int. Rev. d. ges. Hydrobiologie u. Hydrographie 2: 126.

**McDill, B. M.** 1951. Report of water pollution study of Miami River, 1949. Water Pollution Control Unit, Ohio Department of Health. 33 pp.

**Mackenthun, K. M., W. M. VanHorn,** and **R. F. Balch.** 1956. Biological studies of the Fox River and Green Bay. Cooperative report submitted to the Director, Division of Water Pollution Control, Wisconsin. 74 pp.

**Richardson, R. E.** 1921. The small bottom and shore fauna of the middle and lower Illinois River and its connecting lakes, Chillicothe to Grafton: its valuation; its source of food supply and its relation to the fishery. Ill. Nat. Hist. Survey Bull. 13: 363.

———. 1928. The bottom fauna of the middle Illinois River, 1913–1925. Ill. Nat. Hist. Survey Bull. 17: 387.

**Suter, R.** and **E. Moore.** 1922. Stream pollution studies. New York State Conservation Commission.

**Suber, E. W.** 1953. Biological effects of pollution in Michigan waters. Sew Ind. Wastes 25: 79.

**Schiffman, R. H.** 1953. A method of cataloging stream bottom organisms in respect to their pollutional tolerance. Mimeo. Publ. Ill. Dept. of Public Health. 8 pp.

**Weston, R. S.** and **C. E. Turner.** 1917. Studies on the digestion of a sewage-filter effluent by a small and otherwise unpolluted stream. Mass. Inst. Tech., Sanitary Research Lab., and Sewage Exp. Sta. 10: 1.

**Whipple, G. C.** 1948. The microscopy of drinking water (Revised by G. M. Fair and M. C. Whipple). John Wiley and Sons, N. Y. 586 pp.

**Wilson, J. N.** 1953. Effect of Kraft mill wastes on stream bottom fauna. Sew. Ind. Wastes 25: 1210.